ULTRA WIDEBAND ANTENNA FOR ON-BODY COMMUNICATION SYSTEMS

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To my beloved mother and father

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ABSTRACT

Ultra-Wideband (UWB) is the technology declared in IEEE 802.15.6 which is the Ultra-Wideband (UWB) standard for Wireless Body Area Network (WBAN) published in 2012. The need for WBANs come originally from medical purposes, the key component of WBANs is the design of the UWB antenna which faces many challenges, including power consumption, size, frequency, the required band width, and the determination of losses caused by the human body tissues. There are some types of UWB antennas which are used for WBANs exist, The project aims for comparison between the characteristics of these antennas, and then follow it by a design of an antenna, this antenna faces less effects from the human body tissues, and gives a better performance in the simulations, avoiding all the complexities that been mentioned. The Design of the antenna uses CST Microwave Studio, to investigate the characteristics of the proposed antenna and optimize it, also the the fabrication has been done on FR4 PCB substrate, and all the required testing and comparison has been done. The effect of wearable antenna on the human body has been also investigated using homogeneous human body (muscle) model with distance of 5mm. The research works in this paper has demonstrated that UWB antenna using microstrip fed and coaxial probe as radiating element can be used for WBANs without effecting the human body, and achieves a very high bandwidth that can be used to transmit any kind of data. The small size of the antenna also provides no problem for the human comfort.

ABSTRAK

Ultra-Wideband (UWB) adalah teknologi yang diisytiharkan dalam IEEE 802.15.6 yang merupakan Ultra-Wideband (UWB) standard bagi Kawasan Badan Wireless Network (WBAN) yang diterbitkan pada tahun 2012. Keperluan untuk WBANs datang asalnya dari tujuan perubatan, komponen utama daripada WBANs adalah reka bentuk antena UWB yang menghadapi banyak cabaran, termasuk penggunaan kuasa, saiz, kekerapan, lebar jalur yang diperlukan, dan penentuan kerugian yang disebabkan oleh tisu badan manusia. Terdapat beberapa jenis antena UWB yang digunakan untuk WBANs wujud, projek ini bertujuan untuk perbandingan antara ciri-ciri antena ini, dan kemudian mengikutinya oleh reka bentuk antena, antena ini menghadapi kesan kurang daripada tisu-tisu badan manusia, dan memberikan Prestasi yang lebih baik dalam simulasi, mengelak segala kerumitan yang telah disebut. Rekabentuk antena menggunakan CST Microwave Studio, untuk mengkaji ciri-ciri antena yang dicadangkan dan mengoptimumkan ia, juga fabrikasi yang telah dilakukan ke atas papan cetak FR4 PCB substrat, dan semua ujian dan perbandingan yang diperlukan telah dilakukan. Kesan antena dpt dipakai pada tubuh manusia telah juga diuji dengan menggunakan model homogen badan manusia (otot) dengan jarak 5mm. Kerja-kerja penyelidikan dalam kertas ini telah menunjukkan bahawa antena UWB menggunakan mikrostrip makan dan siasatan sepaksi sebagai terpancar unsur boleh digunakan untuk WBANs tanpa melaksanakan tubuh manusia, dan mencapai jalur lebar yang sangat tinggi yang boleh digunakan untuk menghantar apa-apa jenis data. Saiz kecil antena juga tidak memberikan sebarang masalah untuk keselesaan manusia.

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LIST OFABBREVIATIONS

UWB	-	Ultra-wideband
FCC	-	Federal Communication Commission
BCWC	-	Body Centric Wireless Communication
4G	-	Forth Generation
WPAN	-	Wireless Personal Area Network
WBAN	-	Wireless Body Area Network
BSN	-	Body Sensor Network
WSN	-	Wireless Sensor Network
ECG	-	Electrocardiography
FDTD	-	Finite difference time domain technique
MICS	-	Medical Implement Communication Service
ISM	-	Industrial, Scientific and medical
WMTS	-	Wireless Medical Telemetry Service
Ω	-	Ohm
dB	-	Decibel
CST	-	Computer Simulation Software
FR4	-	Fire Retardant Type 4
BW	-	Bandwidth
BW%	-	Bandwidth percentage
PCB	-	Printed Circuit Boards
Hz	-	Hertz
MHz	-	Miga Hertz
GHz	-	Giga Hertz
mm	-	Millimeter
RF	-	Radio Frequency
IEEE	-	Institute of Electrical and Electronic Engineers
VSWR	-	Voltage Standing Wave Ratio

RL	-	Return Loss
SAR	-	Specific Attenuation Rate
EM	-	Electromagnetic
UV	-	Ultraviolet
SMA	-	Subminiature version A Coaxial Connector

LIST OF SYMBOLS

h	-	Dielectric substrate thickness
l	-	Length
w	-	Width
Γ	-	Reflection coefficient
Z_0	-	Characteristic impedance
Z_L	-	Load impedance
λ_r	-	free-space wavelength
V_0^-	-	Reflected voltage
V_0^+	-	Incident voltage
ε_r	-	Dielectric constant of the substrate
t	-	Patch thickness
c	-	Speed of light 3x 10^{-8} m/s
π	-	Pi
η	-	Efficiency
G	-	Gain
S_{11}	-	Reflection coefficient
g	-	Gram
Kg	-	Kilogram
W	-	Watt

CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless technology has changed our lives during the past two decades and it has become very popular in recent years. Wireless technology is growing very fast throughout the whole world and larger numbers of people are relying on it, directly or indirectly. Rapid development in wireless technology, in addition with continuous miniaturization of sensors, is leading to a new generation of wearable devices. With the increasing presence of wireless communication in our daily lives, body-centric wireless communications (BCWCs) systems will be a focal point in the development of the fourth generation (4G) mobile communications system [1-3].

Body-centric wireless networks consist of a number of wireless sensors that placed on the human body or in close to it in the range effected by it. These sensors are required to communicate with other on-body units, with external base stations, or with wireless implants [see Fig. 1.1].

The applications of BCWC vary from low-power low-data-rate communications in healthcare services, to high-data-rate networks used for personal entertainment. The concept of BCWC includes wireless body area networks (WBANs), wireless personal area networks (WPANs) and body sensor networks (BSNs). A WPAN usually refers as the communication between the wearable device and off-body base units, while WBAN consists of several wireless sensor nodes scattered on the human body, communicating with an on-body base unit. The BSN extended from the wireless sensor network (WSN), and mainly concerned with human physiological data acquisition and communication through a combination of bio-medical and wireless sensors. A very important subject related to BCWC is convergence, in which several functions, capabilities and technologies merged into a single terminal that will embrace both local and global connectivity.

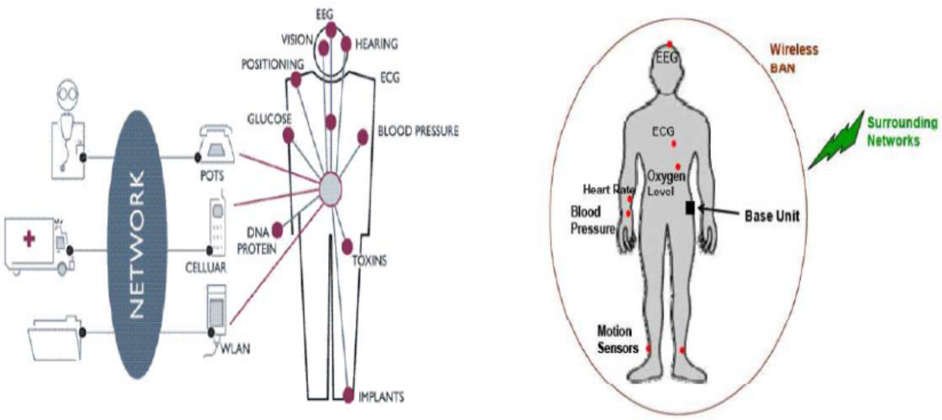

Figure 1. 1 (a) An example of BCWNs for health monitoring. (Many sensors on the body to collect information and send them to a base station, which is able to communicate with off-body devices to inform about the condition of the user); (b) Wireless BAN in Healthcare Applications [1, 7].

With the increasing average age of populations in the whole world and the associated rise of healthcare costs, the development of systems for freeing hospital resources is of particular interest in academic and industrial environments. A continuous and remote diagnosis of a patient has been proposed [4-5] by using a "smart" network, where data sets collected from various sensors analyzed in order to allow controlled administration of medicine, as well as the generation of emergency calls. The same concepts discovered an important application in athlete monitoring.

By 2012, it is predicted that on-body wireless sensors could save $25 billion worldwide in annual healthcare costs by providing the capability for remotely monitoring vital signs, such as heart rate, heart Electrocardiography (ECG), blood glucose monitoring, and blood oxygen, for recovering patients and the elderly [6].

The main disadvantage of current used body-worn systems is using the wired communications, which is undesirable because its inconvenience to be used. Other solution been proposed to solve this problems, one of it is using of smart textiles. Smart clothes imply the need for a special garment to be worn, which may conflict with the user's personal preferences [8]. Body-centric wireless network (BCWN) presents an apparent option and is aiming to provide low power systems with constant availability, re-configurability and unobtrusiveness. However, such networks face many challenges that need to be accounted, before they can be fully deployed for real life applications. Body-worn antennas, on-body wireless communication channels and systems are essential components in the body-centric wireless networks, which are the main motivations of the investigations and analyses presented in this project.

Body-centric wireless networks should provide cost-effective solutions and guarantee the mobility and freedom desired by the users. Therefore, the various components of the radio system should provide lightweight and low power consumption to avoid short battery life and unwanted obtrusiveness to the user. One of the major issues in designing such a wireless system is to understand the effect of the human body on the antenna parameters and on the radio propagation channels. The design of body-worn and hand-held devices has many other aspects to take into account, including the safety for the user, the dimensions, and the cost [1].

1.2 Project Motivation

Antennas are the most important part of the wearable devices and they are important to optimize the performance of the radio system. When we set an antenna close to the human body (lossy medium), it changes in the performance compare to its work in the free space. For on-body communication antennas, the radiation efficiency and gain decrease in the presence of the human body close to the antenna. Due to the characteristics on body tissues called “electromagnetic absorption”, which gives frequency-detuning, distortion in the radiation pattern and instability of the antenna impedance. The significance and nature of these effects are system-specific, and depend on the propagation environment, the physical constraints on the antenna itself and the antenna type. They are also frequency-dependent; e.g., a radio wave may penetrate more into the human body at low frequencies, whilst dissipate more at high frequencies.

The biggest difference between conventional wireless systems and BCWC is the channel that used for the communication. Where the human body tissue is a lossy path; hence, the wave propagating within the WBAN faces large attenuation before reaching the specified receiver. Since the human body is hostile in regards to attenuating and distorting the transmitted signal, the design of a reliable and power-efficient wireless system requires accurate analysis and understanding of the radio propagation. Furthermore, the characteristics of body-centric radio channels are subject-specific and depend on many factors, such as the frequency of operation and the antenna radiation. All these issues, if not accurately examined, can lead to increased transmission errors or, in extreme cases, loss of a marginal communication link. Therefore, it is very important to understand the human body effects on the antenna performance parameters and on the radio propagation channels in order to design an ideal wireless system for BCWNs.

Recently, there was interest increase in the development for of the design of wearable UWB (3.1-10.6 GHz) antennas; at all, until now there was no big development in the design of the wearable antennas. Previously people have studied the effects of the human body on the antenna parameters of performance and on-body radio propagation channels at UWB frequencies. However, the previous studies are limited, because of considering limited number of antennas for UWB. In addition, all the performance parameters close to the body for the UWB antennas have not been investigated and analyzed thoroughly.

A complete parametrical studies and statistical analysis addressing the effect over the performance parameters do to the human body for various types UWB antennas will help in selecting the best antenna for body-centric wireless communications and enable the development of guidelines useful for the system designers. In addition, there is need of a complete list of antenna specifications and design guidelines for UWB body-centric wireless communication systems. To the best knowledge of the author, the above-mentioned work not been done before.

For power-efficient and reliable body-centric wireless communications, there is a need of designing the suitable body-worn antenna. In BCWCs, communications among on-body devices are required, as well as communications with external base stations. Low power consumption is required in Body-centric wireless devices to extend the battery life as a result for the body-worn devices, in addition there is need to give power-efficient (minimize link loss) and reliable on-body communications. Optimization of antenna radiation pattern at different frequency bands is needed. In this regards, there is a need for an antenna that works at different frequency bands, having diverse radiation modes.

Researchers have been thoroughly investigating ultra wideband on-body radio propagation channels. However, the sizes and shapes of the different human bodies will affect the propagation path and lead to different system performances. From the subject-specific on-body radio, propagation prospective very limited work presented in literature that mostly based on the finite difference time domain technique (FDTD). There was not a sufficiently thorough analysis and the number of digital human phantom test subjects was limited in this study. However, a thorough investigation and analysis of subject-specific on-body radio propagation channels for a wider number of people with different shapes, sizes and heights in UWB systems are required. A comparison of the on-body radio channels' subject specificity for UWB is required in order to be able to specify which technology is more subject-specific.

1.3 Project Objective

The objective of the work presented in this project is to investigate, characterize, analyze and specify the antenna and the radio propagation channels for on-body communications. This done through a combination of numerical simulations and measurement campaigns. The main objectives of the study include:

1. Design a novel dual-band and dual-mode (diverse radiation pattern) antenna for power efficient and reliable cooperative on-body communications.

2. Investigation of subject-specific ultra wideband (3.1-10.6 GHz) on-body radio propagation channels for on-body communication systems.

1.4 Scope of the Project

The scope of this project is to study proposed UWB antenna design to achieve the required frequency response (3000MHz to 10000 MHz). The project started with the Simulation of radiation pattern and reflection coefficients and bandwidth response by using Computer Simulation Technology (CST), then by Design, fabrication and prototype measurement. Finally, parameters such as radiation-pattern return-loss and bandwidth response between actual antenna and simulated design will be analyzed. There are seven elements in the scope to be carried out as per below details:

1. Literature on the concept of UWB antenna. Review on previous work related to the UWB antenna.
2. Design and simulation of the UWB antenna by using the concept of patch micro strip antenna operating at the frequency band (3GHz to 10GHz).
3. Optimization of the antenna design to fulfill antenna specification.
4. Fabrication of the selected antenna design.
5. Test and measurement of the fabricated antenna.
6. Analysis, discussion and assessment on the antenna properties.
7. Final report and presentation.

1.5 Methodology

In order to achieve target objective many approaches taken. Project workflow has been organized and simplified as shown in the flow chart in Figure 1.2. Design methodology will be discussed in details in chapter 3. The UWB antenna for On-Body Communication will be simulated using CST Microwave Studio 2012 software. Then, the optimized simulation UWB antenna will be fabricated using wet etching process and followed by the measurement process. After that, analysis of simulation and measurement results are discussed.

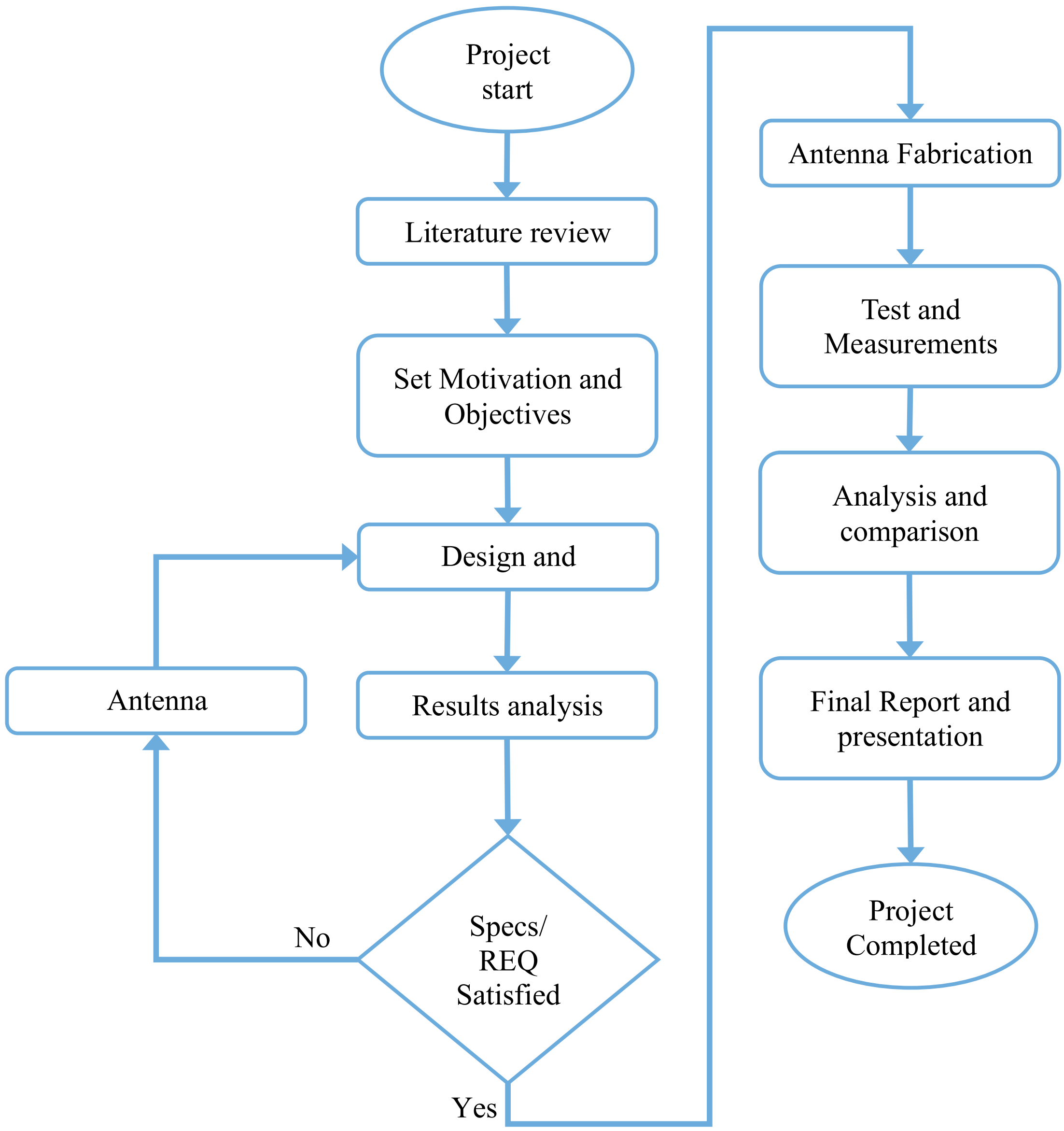

Figure 1. 2 Flowchart of the antenna Development

1.6 Project Organization

Following this introductory chapter, the rest of the thesis organized as follow:

Chapter 2 introduces the allocation of the frequency spectrum for body-centric wireless communication. An overview of the main technologies available for body-centric wireless communications. In addition, introduces antenna and radio propagation for on-body communications. Fundamental antenna parameters also discussed in this section. Moreover, this chapter illustrates and describes the electrical properties of human body tissues. It also discusses the parameters ruling the radio propagation in multipath channels. Towards the end of this chapter, an extensive literature review on the state-of-the-art in the development of body worn antennas and radio propagation channels provided.

Chapter 3 introduces the project methodology, the design steps and an introduction for the simulation software used in the simulation process. And the steps of that will be taken to fabricate the antenna.

Chapter 4 investigates and compares the on-body performance parameters (frequency shifting, impedance matching, bandwidth, gain, radiation efficiency, radiation pattern, pulse fidelity and polarization) of the ultra wideband (3.1-10.6 GHz) antenna. It also investigates the impact of the antenna on the body radio channel characteristics at 3-10 GHz. Statistical analysis is performed in order to evaluate the on-body antenna parameters. Some parameters that control the on-body performances of the UWB antennas also discussed here. UWB antenna specifications and design guidelines for WBANs provided. Finally draws some conclusions, and preliminary results.

Chapter 5 presents investigation of the designed UWB antenna for on-body communications. And study its characteristics after taking the measurements of the fabricated antenna. At the end, a novel design for an UWB antenna for on-body communication systems provided.

Chapter 6 provides a summary of the main contributions and findings of the study and concludes the accomplished work packages. It also introduces suggestions for future works.

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